Searching for Weak Lensing in the SDSS Supernovae

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ABSTRACT

Type Ia supernovae from the 2005 and 2006 Sloan Digital Sky Survey (SDSS) Supernovae Search are analyzed for indications of weak lensing. A two-point cross-correlation function is calculated for each supernova considering a region within ten arcminutes of the supernova. Each galaxy's influence on the correlation is weighted based on distance from the supernova. The correlation between two-point cross-correlation and Hubble residual shows evidence of weak lensing at the 97% confidence level. The correlation measured is not strong evidence for weak lensing but the analysis of a greater number of supernovae (2007 SDSS SN) could allow for a statistically significant determination.

I. PURPOSE

The purpose of this project was to determine if weak lensing has an effect on the observed brightness of type Ia supernovae. Williams and Song (2004), used high red-shift supernovae to search for the effects of weak lensing and they found a much stronger weak lensing signal than theory predicted. Williams and Song (2004) analyzed supernovae from two sources, the High-z Supernovae Search Team and Supernova Cosmology Project, and their galaxies from the APM galaxies. In their analysis, they drew circles with a radius of ten minutes around each supernovae and counted up the galaxies. Then they compared this number to the number in a circle of the same radius, randomly placed on the same plate. The intent of this project is check Williams and Song's results using a different source of data, a larger number of supernovae, and a different method of analysis to detect weak lensing.

2. INTRODUCTION

Type Ia supernovae are known as "standard candles." The supernovae explode from white dwarfs and, using their light curves, their luminosity can be determined more accurately than other distant objects. From comparing intrinsic brightness to the apparent brightness astronomers can calculate what the distance to the supernovae is. However, factors such as dust or gravitational lensing can affect the observed brightness and result in an incorrect distance estimate.

One of the possible causes of these differences is weak lensing. Weak lensing is a particular aspect of gravitational lensing, the bending of light by gravity predicted by Einstein's General Theory of Relativity, and unique from other forms of gravitational lensing because it results from the mass density fluctuations in the large-scale structure of the Universe.

By relating the number and position of galaxies in the path of the light from type Ia supernovae, as calculated by a two-point correlation function, to the difference between the predicted observable brightness and the actual observed brightness as given by the Hubble residual, the presence or absence of lensing may be determined.

3. METHOD

The data for this research came from the Sloan Digital Sky Survey (SDSS) Supernovae Search (Frieman et al 2008) and the analysis was done using Interactive Data Language (IDL), a data analysis language, and mySQL, an open source database system.

Beginning with 97 supernovae from the 2005 SDSS, first a mySQL query was done to retrieve data for all galaxies in between each supernova and their location relative to our line of sight, within a square section of sky forty arcminutes on a side centered on the supernovae. The photometric red shift for each galaxy was also retrieved, but galaxies without information on their red shift are not used. The list of galaxies is then limited to include only galaxies closer than the supernova and those within a circular space within twenty arcminutes of the supernovae. Because the area in which the SDSS was taken is a narrow band of the sky, care was taken to see if part of the region overlapped the edge of the survey. This was accounted for by subtracting the area of section of the region that fell outside the survey before the calculations for the two-point cross-correlation were made. First, a check was made for the region around the supernova overlapping the edge of survey, and then, if it is found to overlap, a calculation of the noncircular area of the region is done, using the algorithm:

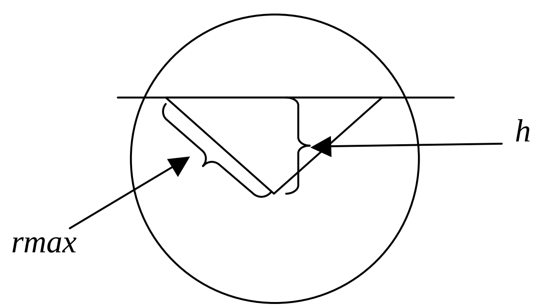

Figure 1 – Region around a supernova overlapping the edge of the survey area.

Set the limits of the survey:

left=[abs(-60-RA_{SN}) lt (rmax/60)]

right=[abs(60- RA_{SN}) lt (rmax/60)]

top=[abs(1.25866- Dec_{SN}) lt (rmax/60)]

bottom=[abs(-1.25866- Dec_{SN}) lt (rmax/60)]

Test if the region overlaps the survey then the area is calculated: (The process is repeated for the right, top, and bottom.)

if [left and (not (bottom) and not(top))] then begin

h=abs(-60- RA_{SN})

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totarea=(3.14159*rmax^2)-[(acos((h*60)/rmax)*rmax^2)-sqrt(rmax^2-(h*60)^2)*(h*60))]
endif
```

If the region does not overlap the survey the area is simply a circle.

```
if not(top) AND not(bottom) AND not(left) AND not(right) then begin
totarea=3.14159*rmax^2
endif
```

A test was also done to see if any of the regions fell in a corner, overlapping two sides. None of the supernovae were on a corner.

A similar process is undertaken to calculate the area of each of the radial bins. The region around the supernovae is divided into two bins, one for the circle with a radius of ten arcminutes closest to the supernovae and another for the ring outside of that circle with a width of ten arcminutes. The test if the region overlaps the survey is repeated for each bin, and then area of the bin is calculated.

Each galaxy along the path of light from the supernovae is weighted based on its distance from the supernovae.

$$m(Z)=[(Z_{SN}-Z_{gal}) \cdot Z_{gal}]/ \tfrac{1}{4} Z_{SN}^2$$

Galaxies half way between our perspective and the supernovae have the greatest effect on lensing and are given the most weight, while galaxies very near the supernovae or our perspective have less effect and are given less weight.

The two-point cross-correlation for each supernovae is calculated by dividing the sum of the weights of the galaxies in that area (m_{bin}) by the sum of the weights of all the galaxies (m_{tot}) multiplied by the ratio of the area of the section we counted in to the total area.

$$w = m_{bin} / [m_{tot} \cdot A_{bin}/A_{tot}] - 1$$

A value for w less than zero indicates a low mass density in front of the supernova which should "demagnify" while a value for w greater than zero indicates a high mass density which magnifies.

The error of the two-point cross-correlation is then calculated:

$$error_w = 1/sqrt[m_{tot} \bullet A_{bin}/A_{tot}]$$

After analyzing the data from the 2005 SDSS supernovae, the program was used to analyze 88 2006 SDSS supernovae, and then all 185 supernovae together.

4. RESULTS

To determine if there is a correlation present, the two-point cross-correlation of each supernova was plotted versus its Hubble residual value. Plots were done for the 2005 supernovae, the 2006 supernovae, and the set of both together. A linear fit was determined by the minimization of χ^2:

$$m=1/[(\Sigma(1/err_{HR}^2) \bullet \Sigma(w^2/err_{HR}^2)) - \Sigma(w/err_{HR}^2)] \bullet [(\Sigma(1/err_{HR}^2) \bullet \Sigma(w*HR/\ err_{HR}^2)) - (\Sigma(w/err_{HR}^2) \bullet \Sigma(HR/err_{HR}^2))]$$

$$b=1/[(\Sigma(1/err_{HR}^2) \bullet \Sigma(w^2/err_{HR}^2)) - \Sigma(w/err_{HR}^2)] \bullet [(\Sigma(w^2/err_{HR}^2) \bullet \Sigma(HR/err_{HR}^2)) -(\Sigma(w/err_{HR}^2) \bullet \Sigma(w \bullet HR/err_{HR}^2))]$$

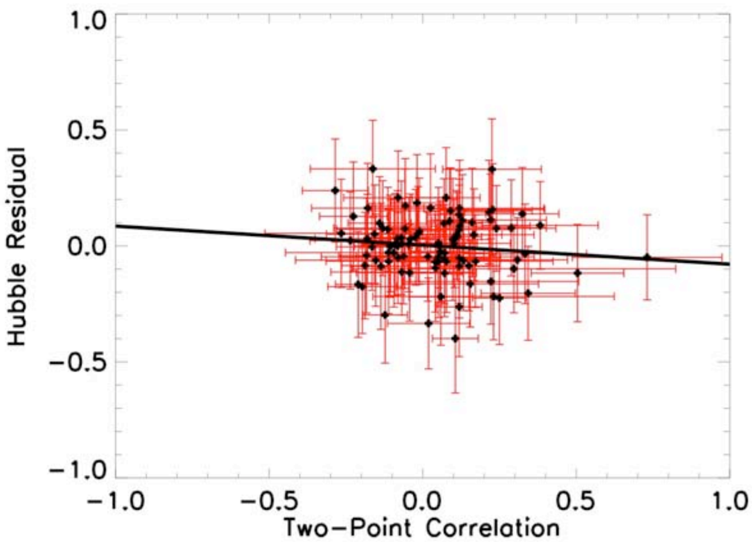

Figure 2 – Plot of 2005 supernovae, two-point correlation function vs. Hubble residual.

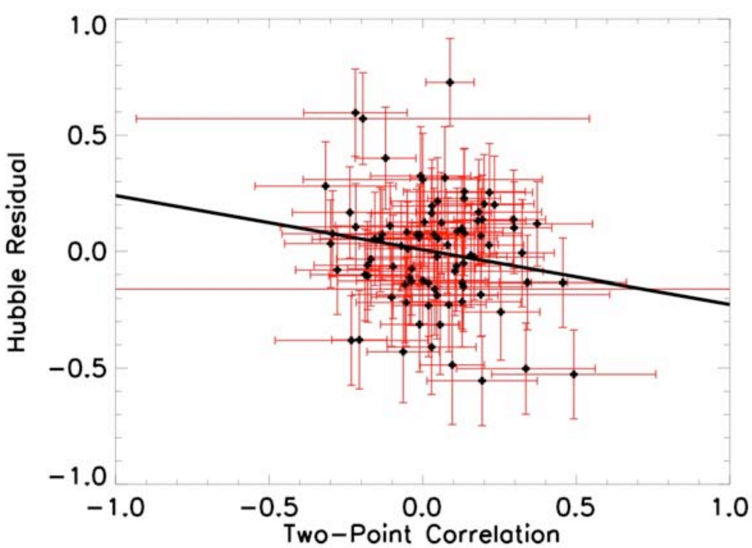

Figure 3 - Plot of 2006 supernovae, two-point correlation function vs. Hubble residual.

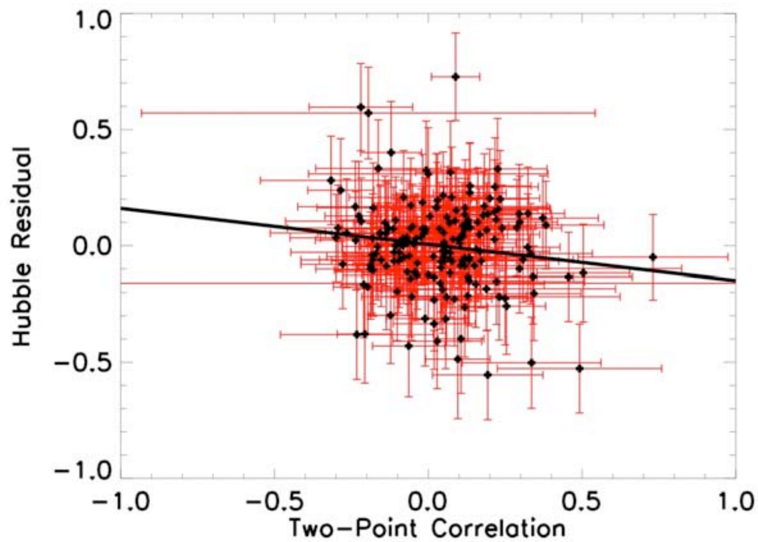

Figure 4 - Plot of both 2005 and 2006 supernovae, two-point correlation function vs. Hubble residual.

Table 1
Slope of Linear Fits

Plot	Slope
2005	-0.0821422
2006	-0.233140
Both	-0.155045

In order to determine their significance, these results were compared to the likelihood of them appearing randomly. Hubble residual values were scrambled using a random number generator in IDL and plotted against the two-point correlation values, then slope of the linear fit was found. This process was repeated ten thousand times and the slopes produced were plotted in a histogram with one hundred bins. The statistical significance was calculated.

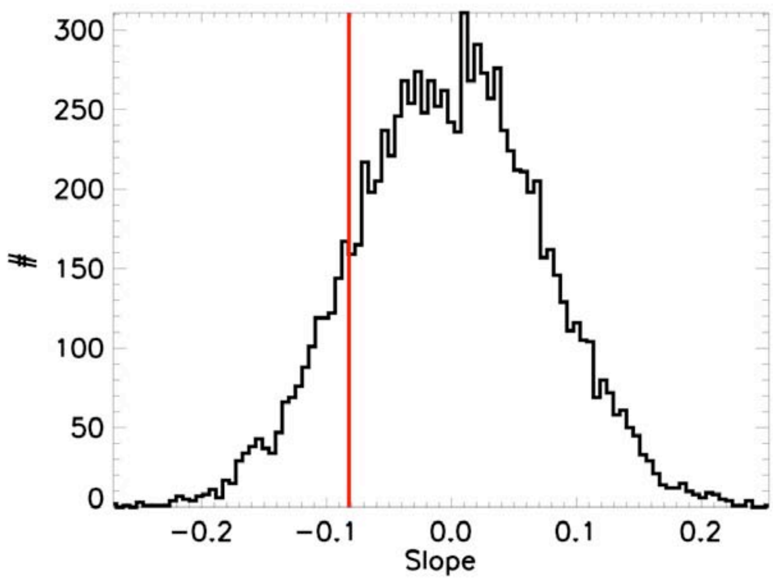

Figure 5 – Plot of slope of the fit line of the two-point correlation for 2005 supernovae vs. number of instances calculated randomly.

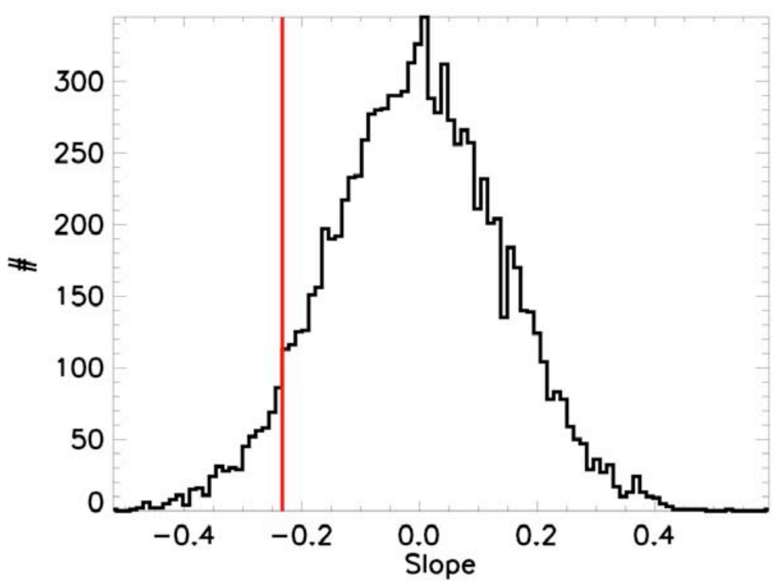

Figure 6 - Plot of slope of the fit line of the two-point correlation for 2006 supernovae vs. number of instances calculated randomly.

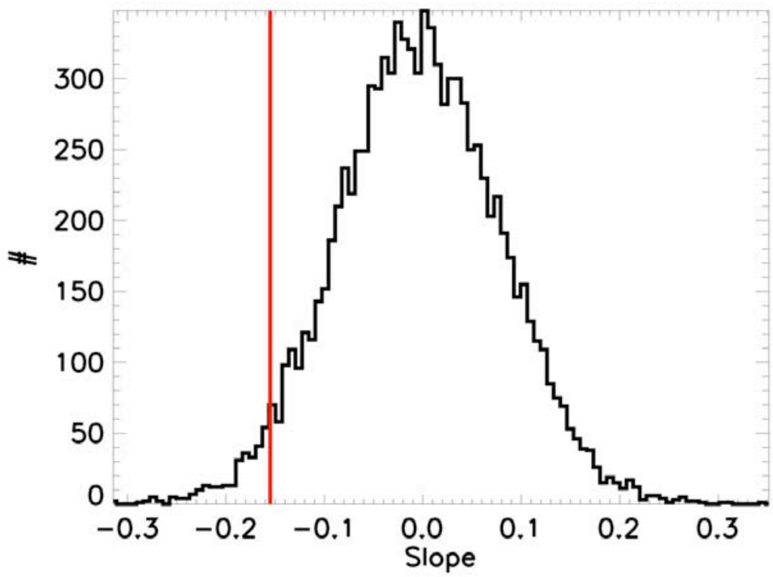

Figure 7 – Plot of slope of the fit line of the two-point correlation for 2005 and 2006 supernovae vs. number of instances calculated randomly.

Table 2
Interpretation of Results

Plot	Significance
2005	0.1541
2006	0.0587
Both	0.0312

5. CONCLUSIONS

Our analysis did not conclusively show the presence of weak lensing. The trends of the results are consistent with theory, however, the correlation detected in this analysis is not significant.

In comparing these results with the results of Williams and Song we adjusted the range of the two-point correlation values to fit their range of data on the x-axis, so the slopes would be on the same scale.

$$\Delta Mag_{SN}/\Delta N_{>}/N = \Delta HR/\Delta w \bullet (w_{max}-w_{min})$$

Williams and Song calculated the slope to be -0.373. Our slope adjusted to fit Williams and Song’s scale is -0.06427, which is much smaller. Williams and Song’s slope adjusted to our scale is -0.900, which is inconsistent with our observations. It is of note that Williams and Song's analysis was of more distant supernovae.

Our analysis supports the theoretical predictions that weak lensing does exist, at a low level of significance. It is also shows that the results demonstrated in the Williams and Song paper show too large an effect compared to our results. Finally, by increasing the number of supernovae in the future with the addition of the 2007 SDSS supernovae it could be possible to have enough data for the results to be significant.

6. ACKNOWLEDGEMENTS

I would like to thank several people who helped in this project. First, my Professor, Peter Garnavich, whose knowledge, guidance, and patience were essential to the success of this summer. Also, Brian Hayden and Collin McClelland, who taught me IDL and helped with many questions throughout this process. Thanks as well to Professor Umesh Garg for giving me the opportunity to be a part of this REU. Finally, to the all the 2008 Physics REUs at Notre Dame, on a scale of one to three, this summer is of course a two, but it is definitely a truncated two.

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